Comparison of Pupillary Responses to Low and High Frequency Lighting

Report to the Lighting Research Institute (LRI)

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Abstract

Using infrared pupillometry the pupil sizes of 24 healthy young adult subjects were compared under indirect illumination from four different light sources operating at either the 60 Hertz line frequency or at a high frequency of approximately 30 Kilohertz. Several different luminance levels were used in the frequency comparison ranging from 5 to 160 candelas per square meter (cd/m^2). Under conditions where pupil size differences have been observed due to both spectral composition of the lamps and luminance changes, no differences were found between high and low frequency operation within the accuracy of these experiments.

Introduction

During the past year studies have been ongoing by LBL/UCSF to examine pupillary responses to different lamps where the primary distinction between lamps is the differences in their spectral power distribution. The type of lamps being investigated are commonly used in general lighting namely incandescent, fluorescent, high-pressure sodium and low-pressure sodium. Since these lamps have inherent flicker modulations ranging from 5% to 100% modulation, our investigations concerned with pupillary responses to the different lamp spectral power distributions have been carried out by operating all the gas discharge lamps at the high frequency of approximately 30 Kilohertz. At this frequency these lamps have very small modulations and are seen by the visual system as equivalent to d.c. operation. Thus, any compounding condition due to flicker was eliminated for studies involving spectral comparisons.

However, since lamps in general use are more frequently operated at the line frequency of 60 Hertz it is essential to compare pupil responses for high and low frequency operation in order to determine if low frequency modulation can influence the pupil size differences ellicited in previous work related to the spectral output of the lamps. In addition, a further need to study differences in the low/high frequency responses occurs because of observations we made in an early pilot study of pupil sizes comparing incandescent lamps with both low and high frequency operated high pressure sodium lamps. In that pilot study of six subjects, a pupil size difference between the high and low frequency operation was observed, but it lacked statistical significance. Power analysis of the results predicted that a study of an additional six subjects had a reasonable likelihood of showing a statistically

significant result if indeed the effect was real, rather than due to chance sampling in the pilot study.

Methods

Twenty-four young healthy adult Caucasian paid volunteers, males and females, between 17 and 20 years of age participated in this study. All were tested to have 20/20 vision and were reported to be free of drugs.

All testing took place in a sound attenuating RF shielded chamber (Erik A. Lindgren & Associates, Chicago, Illinois) measuring 2.3 meters high and 2 by 2 meters square. The subject sat in a chair and faced a metal wall coated with Kodak Reflective Paint (spectrally flat reflectance) which had few visual features. That wall was about 1.1 meter distant, and was bathed by lighting fixtures mounted above the subject's head, shielded from direct view. The rest of the chamber was lit only by reflected light.

The electrical lights used in this study were daylight fluorescent (DF), low and high pressure sodium (LPS, HPS) lamps and a bluish-white fluorescent (Sylvania HX-31 Phosphor) referred to here as HX-31. All of these lamps have 120 Hertz modulations greater than 90% when energized by 60 Hertz line frequency and thus should be most likely to produce an effect of temporal modulation. The spectral output of the LPS is sharply peaked in the yellow region in the visible spectrum while the HPS, HX-31 and DF are broad band sources each with very different spectral power distributions. The HX-31 has much more blue than the DF which in turn has more blue than the HPS. Thus, the four lamps under investigation provided a wide range of spectral distributions which included spectra both deficient

in blue and rich in blue (since the blue end of the spectrum is a major determinant of pupil responses).

Continuous monitoring of the illuminance of the lamps was accomplished by a Tecktronix J-16 digital photometer mounted on the directly illuminated front wall at approximately subject eye-level. A Spectra Pritchard photometer (Model 1980A-PL) was mounted over the left shoulder of the subject and measured the luminance of a small area of the wall (6 minutes of arc field) directly in front of the subject. Table 1 lists the luminance values used for each of the lamps, the number of subjects, the flicker modulation in percent measured as (Max-Min/Max+Min). These modulations were measured in our lighting laboratory at LBL using a photo diode.

Table 1

Lamp Type	Luminance Values cd/m^2	Number of Subjects	Percent Modulation
HX-31 (40 Watt)	15, 30, 45	5	100
HPS (35 Watt)	30, 60, 90	6	95
DL (40 Watt)	30, 100, 160	7	90.5
LPS (18 Watt)	5	6	100

Infrared pupillometry was carried out using a MicroMeasurements, Inc. pupillometer which measured pupil area with built-in corrections for angle of gaze and the distortions produced by reflecting the pupil image through a front-surfaced mirror mounted slightly below the direct line of vision (thus permitting the subject

to view the wall rather than either the mirror or the video camera). The pupillometer output was digitally read by a PDP-8 computer which controlled data acquisition and then transmitted the data files to a PDP-11/44 computer for further analysis and statistical tests.

The subject practiced coming up to the chin rest of the pupillometer and centering his/her gaze so that the pupil image was centered on the pupil monitor, then sitting back to relax between recording periods. Subjects were instructed to maintain their visual direction towards the front wall, fixating upon a small visual point during recordings, and to not look into shadows between recordings. To confirm the following of these instructions, the eye position during recordings was observed via the pupillometer monitor, and between recordings via a second video monitor showing the subject's face. In addition, a continuous recording of the pupillary response was accomplished with a video tape recorder (Hitachi VT-9700A) and a FOR VT-300 Video Timer. For each five second recording, when the subject was positioned so that the pupil was properly recorded, he/she was instructed, via an intercom, to prepare for a recording by blinking, swallowing or moving, and then when fully ready, to press a button upon which a finger rested. Having the subject start the recording period resulted in significantly less blink artifacts. Pupil area was recorded at 20 Hertz for five seconds, a total of 100 data points per recording.

Each subject was acclimatized inside the exposure chamber for 30 minutes prior to testing under the lowest intensity of light. For the HPS exposure twenty consecutive recordings of five second duration were made under each light condition with an inter-recording interval of approximately thirty seconds. The average pupil area over the first 16 artifact-free five second recordings was taken as

the average pupillary response per light condition. For the other three lamps five consecutive readings were made with the first five second reading removed from the subsequent data set.

Results

Figure 1 shows graphs of pupil area in units of square millimeters plotted versus luminance in scotopic candelas per square meter. In each plot both the normal line frequency data and the high frequency data are shown. It is apparent from these plots that if there is any difference between low and high frequency response it is quite small. Table 2 gives the mean at each of the luminance values for 60 Hertz and high frequency operation for the four lamps averaged over all subjects. Also shown in Table 2 is how large a difference (between high and low frequency response) would be necessary to reach statistical significance (with 80% probability) given the conditions of our experiment such as: the between subject variances and sample size when all the luminance values for a given lamp have been combined. In addition Table 2 lists the mean differences and standard error between high and low frequency operation for each lamp.

For each of the three lamps where luminance was varied a two-way repeated measures analysis of variance (ANOVA) was carried out with light level and frequency of operation as the main effects while for the LPS only modulation was evaluated by the one-way repeated measures ANOVA.

The results of these analyses are summarized in Table 3 in terms of the P-values. These values indicate that there is a high probability that any differences observed between high and low frequency operation are due to chance, i.e., there are

no differences in pupil area between high frequency and low frequency operation, while the differences occurring for different intensities are highly significant.

Table 2

	Number Subjects	Luminance (cd/m^2)	Pupil Area (mm^2) Frequency Low	Pupil Area (mm^2) Frequency High	Mean Difference (High-Low) & Standard Error	Significant Difference Detectable with 80% Probability
HX-31	6	15	18.9	19.0	-0.66 ± 0.64	2.9 mm^2
		30	16.0	17.0		
		45	14.7	15.5		
HPS	6	30	34.9	32.9	-0.99 ± 2.38	8.7
		60	26.2	25.2		
		90	22.1	23.8		
DL	7	30	13.8	13.8	0.001 ± 0.2	0.79
		100	8.5	8.7		
		160	7.6	7.4		
LPS	6	5	25.2	24.2	-0.97 ± 1.4	6.2

Table 3

Lamp Type	P-Value for Differences Due to Frequency	P-Value for Interaction Effects	P-Value for Differences Due to Intensity
HX-31	0.733	0.986	0.002
HPS	0.857	0.508	<0.001
DL	0.988	0.828	<0.001
LPS	0.523	-.- -	-.- -

We conclude that our experiments do not detect an effect of modulation, though they do detect differences due to intensity or spectra (Berman, Jewett, et-al, 1987). Thus, our previous results showing pupillary differences due to spectral differences with lamps with low modulation (high-frequency operation) can be applied to standard line frequency operating conditions of these lamps.

Discussion

Psychophysical flicker responses to lamps used for general lighting are believed to be absent when operated at the line frequency of 60 Hertz, (deLange, 1954) (Brundrett, 1974). More objective physiological responses to temporal modulations in the form of visual evoked potentials (VEP) are consistent with the subjective responses although electroretinograms (ERG) responses have been measured at somewhat higher frequencies (Cavonius, 1972) indicating the possibility that fusion frequencies differ in the various stages in the visual pathway. Since the pathway for pupillary control separates from the visual pathway before the optic nerve reaches the next synapse in the lateral geniculate, there is the possibility that human psychophysical critical fusion frequencies (CFF) may not be an adequate measure of the pupil fusion frequency, i.e., the frequency at which a d.c. source and a flickering source of the same mean intensity produce identical pupil sizes. For example, at frequencies of modulations below the psychophysical CFF, but much above the frequencies at which the pupil can directly follow (maximum of 4 Hertz), (Varju, 1964) has shown that there is a net pupillary contraction. In the work of Varju this frequency dependent mean contraction ceases to be observed at a frequency of approximately 30 Hertz. Since these experiments were carried out in

Maxwellian View conditions (open loop) and since they involved small fields of view (8°), such results cannot be safely extrapolated to conditions of free full field viewing that there should be an absence of a temporal modulation dependent pupillary size effect. Hence the need for the experiments reported here.

In our work with the effect of spectral distribution upon pupil size under conditions of common ambient light levels, the integrated intensity of the scotopic portion of the spectrum was the main determinent of pupil size. In the experiments performed here we have tested for modulation effects with a wide spectrum (daylight fluorescent) and with spectra either deficient (HPS, LPS) or rich (HX-31) in scotopic intensity. In no case was a modulation effect noted, so that we have tested for all possible combinations of scotopic/photopic (rod/cone) interactions. We have also tested modulation of all parts of the spectrum. Hence, we doubt that any single part of the spectrum, nor an interaction between two different narrow spectra will show modulation effect.

Acknowledgements

Financial support for construction and development of this laboratory has been furnished by the U.S. Department of Energy through the Lawrence Berkeley Laboratory. Technical support has been provided by Glenn Saika and Elmer Soriano of U.C.S.F. and Oliver Morse of LBL. Assistance for statistical analysis has been provided by G. Fein of U.C.S.F.

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Figure 1:

Summary Modulation Studies